

Nuclear Electric Propulsion

Thermal energy from a fission reactor must be converted to electrical energy to drive an electric thruster. For Code S missions, power conversion will be done by using the Brayton cycle, Stirling cycle engines, or thermoelectric converters. Manned missions will require MWe power levels, hence either the Brayton or liquid metal Rankine cycle is feasible. Total energy range for scientific deep-space applications is 25-250kWe, while for manned exploration missions, the power levels needed can range from 2-30 MWe.

Brayton conversion cycles systems benefit from high turbine inlet temperatures (up to 2000 K) to increase efficiency, and/or increase the heat rejection temperature, thus lowering radiator mass. Materials challenges include the need to provide materials that will permit safe, efficient, and long-duration operation at high temperature, with minimum mass.

Much excess heat is generated at the high temperatures required for highest efficiency. A major challenge is the dissipation of this heat, and its efficient radiation to space. Radiators are thus a major mass contributor to the overall system of a nuclear electric vehicle, especially for thermodynamic cycles that reject heat at low temperatures. Typical heat radiator rejection temperatures for Brayton cycles are 400-500 K; the liquid metal Rankine typically rejects heat at 900-1000 K. These radiators typically will be 300 m in length and will need to be deployed in situ.

Issues (in order of priority)

1. Deployable large radiator

Need to decrease the size and weight of radiators by increasing the temperature, by improving the thermal characteristics of the material, and improving its tolerance to chemical, impact and radiation damage.

Target is high emissivity coating (>0.9) with an areal density of 2-6 kg/m² with an area of 1443 m², and in a high radiation environment.

High emissivity will reduce surface temperatures and enable higher operating temperatures to be used. This will reduce radiator size.

High thermal conductivity material perpendicular to the radiator surface.

Currently aluminum is used (~50 kg/m²).

Ultramet2000 (HfC/SiC applied by CVD) is being developed to increase the emissivity of the radiating surface, does not ablate, and is not affected by radiation.

Can highly conductive, high temperature, light materials such as polymeric carbon or Be be substituted?

Can coating materials, be developed, applied and tested (e.g. Ultramet2000, HfC/SiC layers prepared by CVD)? How much can computed simulation assist in selection and design? How can thermal diffusivity of such composites be improved?

In addition the possibility of damage by micrometeoroid strikes must be considered.

1. Materials for improved efficiency heat pipes

Light weight require capillary loop heat pipes operating at 1300-2000 K to cool Xe/He to 300-500 K in radiator

15kWe Brayton units have operated for 40,000 hours at 1150 K.

Mo-based alloys using Li as the working fluid are available, but long term behavior of the welds, and the creep resistance are not known.

Can heat pipe materials be developed with high thermal conductivity to remove heat radially including through coatings?

Are thermophysical properties, such as wetting characteristics, viscosity and thermal diffusivity, sufficiently well known at heat pipe operating conditions (including low-g)?

2. Shielding of electronic components

Materials must be less radiation sensitive. Proposed Europa Jupiter mission will experience 1 Mrad behind 100 mils of Al.

Galileo spacecraft suffered failure when 200 miles from Europa. Exposure was estimated as 1 rem/minute. Current capabilities ok for normal missions, but not for close proximity to Jupiter.

Can electronic materials be developed that are less sensitive to radiation, or can the effects of radiation damage be minimized?

3. High temperature electronics

Distribution requires electronic materials with operating characteristics of 300-600°C and lifetimes of 10-15 years in a hostile radiation environment

Higher operating temperatures reduce mass, and improve heat rejection by radiation. Current materials breakdown above 200°C, and have lifetimes of 2-5 years.

What properties limit high temperature utilization of traditional electronic materials?

What new materials can overcome these limitations?

4. Liquids retaining hydrogen at high temperature *(While this is in DOE's field, the fundamental nature of the question may leave an opening for NASA)*

Reduction of mass of reactor possible if hydrogen can be retained by fuel. Normally a liquid hydride which cannot operate above 800°C

Moderating effect reduced when the hydrogen is lost. Development of computational chemistry models is not mature enough to design a material with desired properties.

Is it possible to model and produce a hydrogen-containing liquid which retains the hydrogen at high temperature? Can such a liquid be incorporated into the fuel?

5. Lightweight magnet technology including wires and housings

Electric generator delivers 3-phase power at 200 Vac (in ~10 years) and up to 5000 Vac in 25-30 years

15kWe electric units have been tested for 40,000 hours at 10 K.

What materials are needed for light-weight structural materials and wires to hold the system together?

By use of novel techniques is it possible to produce materials for permanent magnets that will be light weight, have high field strength, and operate at high temperatures?

5. Turbine blades (*other agencies may contribute more than NASA can*)

Efficiency of turbines increases with increased temperature.

1300-2000 K operating at 30,000-60,000 r.p.m. is desired.

Selection of alloys is limited by resistance to creep and fatigue crack growth, with trace impurities for helium (Carbon) contributing. 850°C for 50-60,000 hrs is the current plan. Near-term goal is to reach 1200°C in 10-20 years. (ref. Schleicher, R., A. R. Raffray, and C. P. Wong, <http://www-ferp.ucsd.edu/LIB/REPORT/CONF/ANS00/schleicher.pdf>). Some work on TZM, SiC/SiC composites and advanced carbon-carbon materials has been done.

Can alloys, composites or any materials be designed and fabricated that attain the desired specifications?

5. Bearings, lubricants and seals to operate for 10 years

Turbine operates at 50,000 rpm at 2000K. Lubricants must withstand 385-600 K (Brayton) or 850-1000 K (Rankine) for 4-5 years manned, 10 years (un-manned). High radiation environments (e.g. Europa mission 1 Mrad behind 100 mils Al).

Seals to operate in contact with liquid metals

Graphite, BN, MoS₂ currently used. To 1400 K - BN Paint can be used in vacuum and inert atmospheres.

Can existing materials be developed to meet the needs?